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WIND TUNNEL INVESTIGATION OF THE THROTTLE FOR THE PROPOSED AEDC MULTIPURPOSE LOW SPEED WIND TUNNEL

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ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER
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NOTICES

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FOREWORD

The work reported herein was done at the request of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 6241003F, Project 7778, Task 777812.

The results of research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The research was conducted from June to September 1967 under ARO Project No. PD3814. The manuscript was submitted for publication on July 31, 1968.

This technical report has been reviewed and is approved.

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ABSTRACT

A test was conducted in the V/STOL Pilot Tunnel of the Propulsion Wind Tunnel Facility to determine the effects of the throttle on test section flow and to evaluate the performance of the throttle. The throttle produced no measurable effects on the test section flow as long as the fan was not stalled. The throttle losses should be variable so that the power absorbed by the throttle can be matched to the model power input. Operating the air exchanger at air exchange ratios above 20 percent increased the allowable throttle loss to model power input mismatch. The measured throttle loss coefficients agreed well with predicted performance. Additional testing will be required to determine the effects of the throttle on model forces.

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NOMENCLATURE

A_{th}	Tunnel cross-sectional area at throttle location, ft^2
C_d	Throttle vane drag coefficient, $D/q_T S$
C_T	Throttle loss coefficient, $\Delta p_T/q_T$
CPF	Circuit power factor, $\Delta p_f/q_\infty$
D	Throttle vane drag, lb
I	Turbulence intensity, $\sqrt{\overline{u^2}}/V_\infty \times 100$, percent
p	Local static pressure, psf
p_t	Free-stream total pressure, psf
p_∞	Free-stream static pressure, psf
Δp_f	Fan static pressure rise, psf
Δp_T	Throttle static pressure drop, psf
q_T	Dynamic pressure at throttle location, psf
q_∞	Free-stream dynamic pressure, psf
S	Throttle vane area, ft^2
$\sqrt{\overline{u^2}}$	Root-mean-square value of longitudinal turbulent velocity, ft/sec
V_∞	Free-stream velocity, ft/sec
y	Distance from wall, in.
θ	Throttle flap deflection angle, deg
σ	Throttle solidity, percent

SECTION I
INTRODUCTION

The testing of powered models at very low test section velocities is made much more difficult by the low tunnel power requirements at these velocities. In fact, the model power input to the airstream is frequently more than the power required to maintain the desired test section velocity. Therefore, additional losses must be introduced into the tunnel to absorb the model power input if testing is to be accomplished at low test section velocities. The proposed Multipurpose Low Speed Wind Tunnel incorporates a throttle to absorb the model power and to improve the tunnel speed control at low test section velocities.

The throttle must absorb the required horsepower without disturbing the flow in the test section and with minimum effects on the fan. The location of the air exchanger inlet downstream of the test section further restricts the throttle location and requires that the throttle be located relatively close to the test section. Therefore, tests of the throttle were conducted in the V/STOL Pilot Tunnel to determine the effects of the throttle on test section flow and to evaluate the performance of the throttle.

SECTION II
APPARATUS

2.1 TEST FACILITY

The V/STOL Pilot Tunnel is a low speed, closed-circuit wind tunnel capable of operation at test section velocities from 20 to 270 ft/sec. A schematic of the tunnel is shown in Fig. 1, Appendix I, and a photograph of the tunnel is presented in Fig. 2.

2.2 TEST ARTICLE

The maximum required loss coefficient of the throttle is determined by the horsepower that must be absorbed at the minimum test section velocity. If incompressible flow is assumed, then the required loss coefficient can be written as:

$$C_T = \frac{550\ hp}{q_\infty V_\infty A_{th}} \tag{1}$$

The designed loss coefficient of the throttle tested in the V/STOL Pilot Tunnel was determined by calculating the loss coefficient required to absorb 100 hp at a test section velocity of 20 ft/sec in the proposed Multipurpose Low Speed Wind Tunnel.

The throttle tested in the V/STOL Pilot Tunnel was a scale model of the Multipurpose Low Speed Wind Tunnel throttle except that five vanes were used instead of six. The throttle consisted of five vanes located just aft of the test section plenum shell. Perforated plate flaps on the vanes completely spanned the tunnel when extended and retracted into the vanes with the throttle in an open position. The vanes have a modified NACA symmetrical airfoil section to minimize losses when the flaps are retracted. The location of the throttle is shown in Fig. 1, and additional details are shown in Figs. 3, 4, and 5. The variation of throttle solidity with throttle flap angle is shown in Fig. 6.

2.3 INSTRUMENTATION

The test section dynamic pressure and fan pressure rise were measured with a precision pressure transducer and recorded manually. The tunnel total pressure was measured with a self-balancing precision manometer. The static pressures along the top and one side wall of the test section were measured sequentially with the precision transducer and manually recorded.

The longitudinal component of the test section turbulence intensity in the horizontal plane of the tunnel centerline at station 24 was surveyed with a hot-wire anemometer.

SECTION III
TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

The longitudinal turbulence intensity, fan static pressure rise, and the static pressure distribution were obtained for each throttle flap position. The maximum test section velocity was limited by the maximum allowable stress in the throttle flaps and varied from 160 ft/sec with 15-deg throttle flap deflection to 60 ft/sec with 90-deg throttle flap deflection.

The static pressures along the top wall and one side wall of the test section are normally measured with a 50-tube, oil-filled manometer; however, the resolution at test section velocities below 100 ft/sec is not

very precise. Therefore, for this test, the last six static pressure orifices on these walls were connected to the precision pressure transducer through a set of valves and a manifold. This method gave acceptable resolution, but the pressures had to be read sequentially, and any variation in tunnel speed while the pressures were being read would give erroneous data. Therefore, the test section dynamic pressure was measured with the precision pressure transducer at the beginning and end of each data point, and the data were rejected if the test section dynamic pressure varied more than 2 percent.

3.2 PRECISION OF MEASUREMENTS

The estimated precision of the data obtained during this test is as follows:

	Test section velocity, ft/sec		
	20	60	100
V_∞, ft/sec	±0.625	±0.617	±1.250
Throttle loss coefficient	±0.547	±0.167	±0.216
Circuit power factor	±0.170	±0.052	±0.067
p/p_∞	---	±0.00001	---
Fan speed, rpm	±10	±10	±10

The uncertainties quoted for fan speed were the limits to which the fan speed indicator could be read. The remaining uncertainties were determined by a statistical method based on a 95-percent confidence level and a normal error distribution.

SECTION IV
RESULTS

A typical variation of longitudinal turbulence intensity with distance from the wall with the throttle flaps extended is shown in Fig. 7. The profile shape did not vary with throttle flap deflection angle or test section velocity, although there were variations in the magnitude of the turbulence level.

The variation of the centerline longitudinal turbulence intensity with throttle flap angle is presented in Fig. 8. When operating the tunnel with maximum air exchange ratio, no increase in turbulence level was experienced. However, the turbulence level was found to increase rapidly with increasing throttle flap angle above 45 deg with no air exchange. The fan also began to emit an irregular low frequency noise usually associated with fan stall when the turbulence intensity began to increase.

The variation of the longitudinal turbulence intensity with air exchange ratio when the throttle flaps were at the 90-deg position is presented in Fig. 9. Increasing the air exchange ratio above 20 percent decreased the turbulence intensity and decreased the fan speed required to maintain test section velocity as shown in Fig. 10.

Figure 11 shows the variation of fan speed with throttle flap deflection angle for no air exchange and for maximum air exchange at a test section velocity of 60 ft/sec. This figure shows that for throttle flap deflection angles below 45 deg, the fan speed must be increased to maintain a constant test section velocity while increasing the air exchange ratio from zero to maximum. However, for throttle flap deflection angles above 45 deg, the fan speed must be decreased to maintain a constant test section velocity as the air exchange ratio is increased from zero to maximum. When the throttle flaps are deflected 45 deg, the air exchange ratio has no effect on the fan speed.

The performance of the fan at throttle flap deflection angles above 45 deg without air exchange is characteristic of a severely stalled fan. The decrease in fan speed, turbulence intensity, and fan noise for air exchange ratios above 20 percent indicate that the severity of the fan stall was considerably reduced by the increased mass flow through the fan. Therefore, it was concluded that the increased test section turbulence level at large flap deflections was caused by fan stall rather than by the throttle.

The variation of fan pressure rise with test section velocity for various fan speeds and throttle flap deflection angles is shown in Fig. 12. The constant-rpm lines indicate that the fan may have begun to stall at throttle flap deflection angles as low as 30 deg, although no other indication of fan stall was observed until the throttle flap deflection angle exceeded 45 deg. The full-scale Multipurpose Low Speed Tunnel will have a control system capable of maintaining fan speed within ±0.25 percent of the set point. Therefore, the small variation of test section velocity with throttle flap deflection angle at a constant fan speed suggests that the throttle may provide an effective means for regulating test section velocity below 100 ft/sec if a suitable throttle controller were provided. If the throttle were used to regulate test section velocity, the fan speed would be set to give a test section velocity slightly above the desired velocity. The throttle would then be used to maintain the desired test section velocity.

The variation of circuit power factor with test section velocity for several throttle flap positions is presented in Fig. 13. The circuit

power factor increased as the test section velocity decreased below 60 ft/sec. A portion of this increase may be caused by the decreased accuracy with which the fan pressure coefficient could be read at low velocities. However, the uniform decrease for all throttle flap positions suggests that at least a part of the increase in circuit power factor is attributable to other factors. The most likely reason for this increase seems to be an increase in tunnel skin friction losses with decreasing Reynolds numbers.

The rapid increase in circuit power factor as the throttle flaps are opened will quickly stall a highly loaded fan. The fan may begin experiencing stall over a portion of the fan blades at throttle flap deflection angles as low as 15 deg. Therefore, it is apparent that the throttle losses should be closely matched to model power input to avoid fan stall problems. This will require that the throttle flaps be continuously variable between 0 and 90 deg.

The longitudinal static pressure distributions over the rear half of the test section for various flap deflection angles are presented in Fig. 14. The variation of the static pressure distribution with throttle flap deflection was less than the probable error in measuring the static pressure variation at all flap deflection angles.

The variation of throttle loss coefficient with throttle flap angle is shown in Fig. 15. The loss coefficient of screens and grids for solidity ratios up to 0.3 can be approximated by:

$$\frac{\Delta p}{q} = \frac{C_d \sigma}{(1-\sigma)^2} \tag{2}$$

and the loss coefficient of a sharp-edged perforated plate at an angle, θ, to the airstream can be approximated by:

$$\frac{\Delta p}{q} = \left[\frac{0.5+\sigma}{1-\sigma} \sin\theta\right]^2 \tag{3}$$

Equation (2) is from Ref. 1 and Eq. (3) is from unpublished data. Equation (2) should be valid for predicting throttle losses for throttle flap angles up to 30 deg, and Eq. (3) should predict throttle losses for flap deflection angles near 90 deg. The measured loss coefficients showed good agreement with Eq. (2) for flap deflection angles below 30 deg and with Eq. (3) for flap deflection angles over 60 deg.

Data were also obtained with a jet-in-fuselage model installed in the test section in an attempt to determine if the throttle had any effects on model forces; however, the balance was not sensitive enough to

accurately measure the small forces produced at the low velocities required by the throttle. It has been shown that wake interference is one of the principal sources of errors when testing V/STOL models at low speeds (Ref. 2). The possibility of the throttle affecting the wake of the model, therefore, needs further investigation.

SECTION V
CONCLUSIONS

The following conclusions have been drawn from the results obtained:

1. The throttle produced no measurable effects on the test section flow without a model installed as long as the fan was not stalled.
2. The throttle losses should be continuously variable so that the power absorbed by the throttle can be matched to model power input.
3. Operating the air exchanger at air exchange ratios above 20 percent increases the allowable throttle loss to model power mismatch.
4. The measured throttle loss coefficient agrees well with predicted performance.
5. Additional testing is required to determine the effects of the throttle on model forces.

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1. Hoerner, Sighard F. "Fluid Dynamic Drag." Published by the Author, 1965.
2. Heyson, Harry H. "Linearized Theory of Wind-Tunnel Jet-Boundary Corrections and Ground Effect for VTOL-STOL Aircraft." NASA TR-R-124, 1962.

APPENDIX
ILLUSTRATIONS

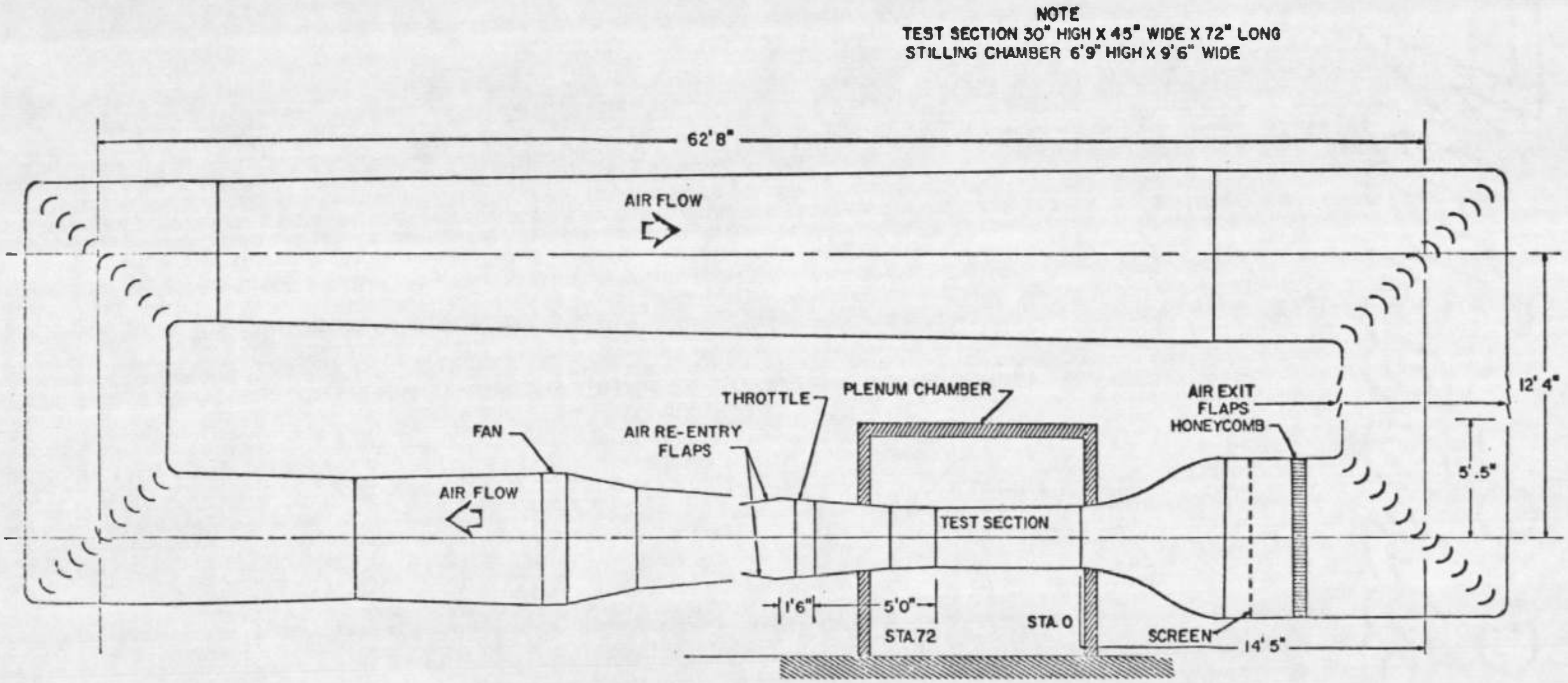


Fig. 1 General Arrangement

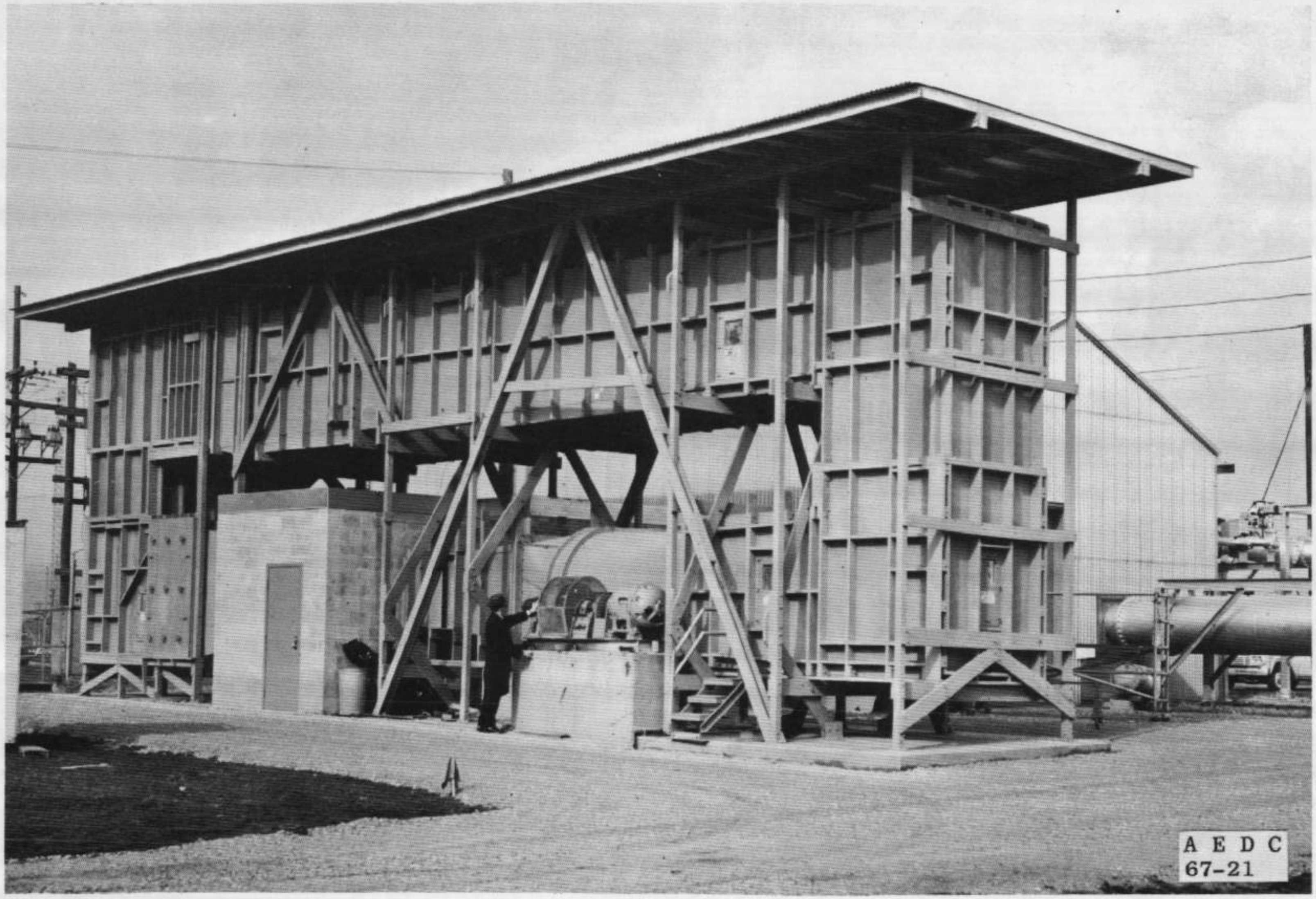


Fig. 2 V/STOL Pilot Tunnel

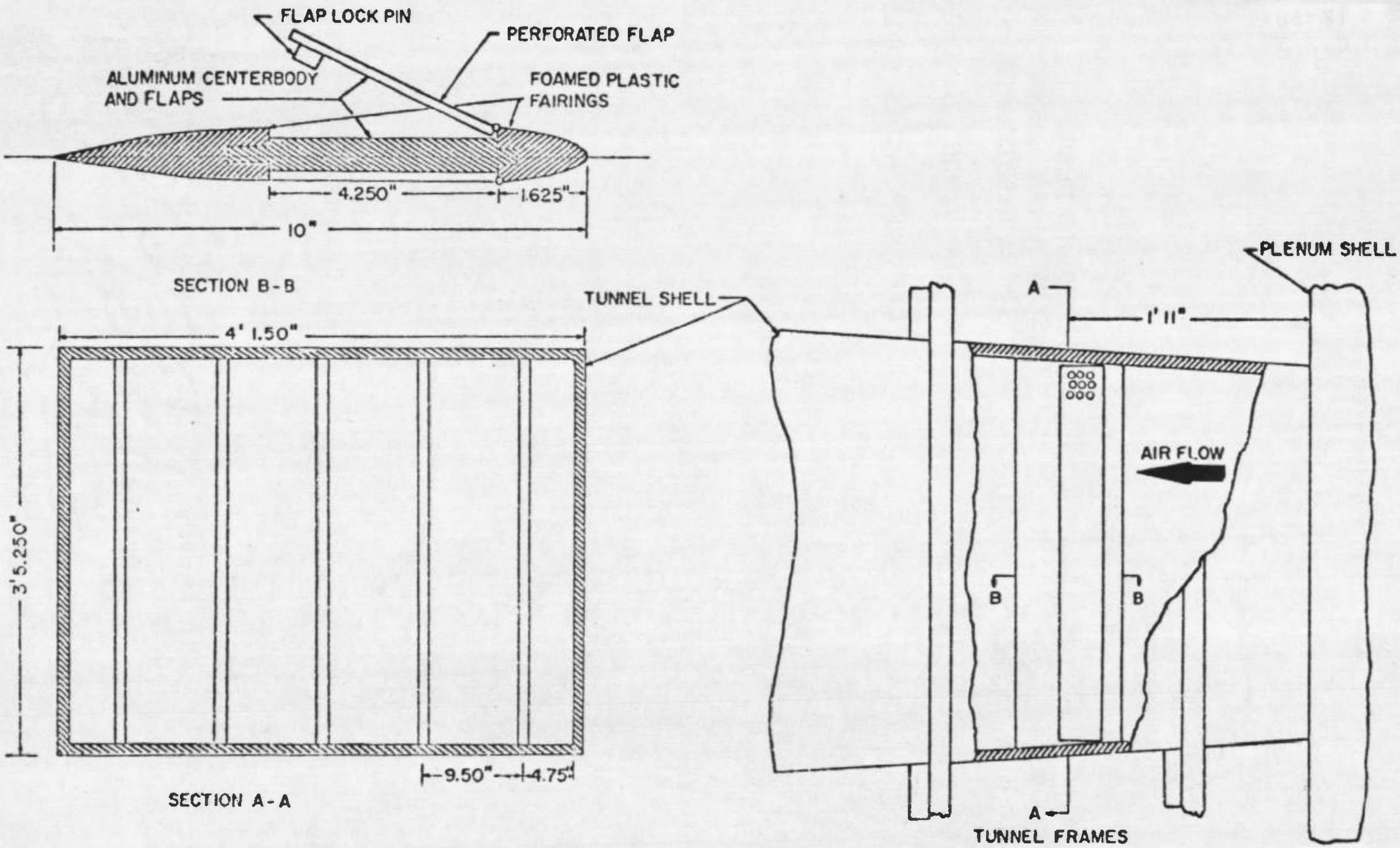


Fig. 3 Throttle Details

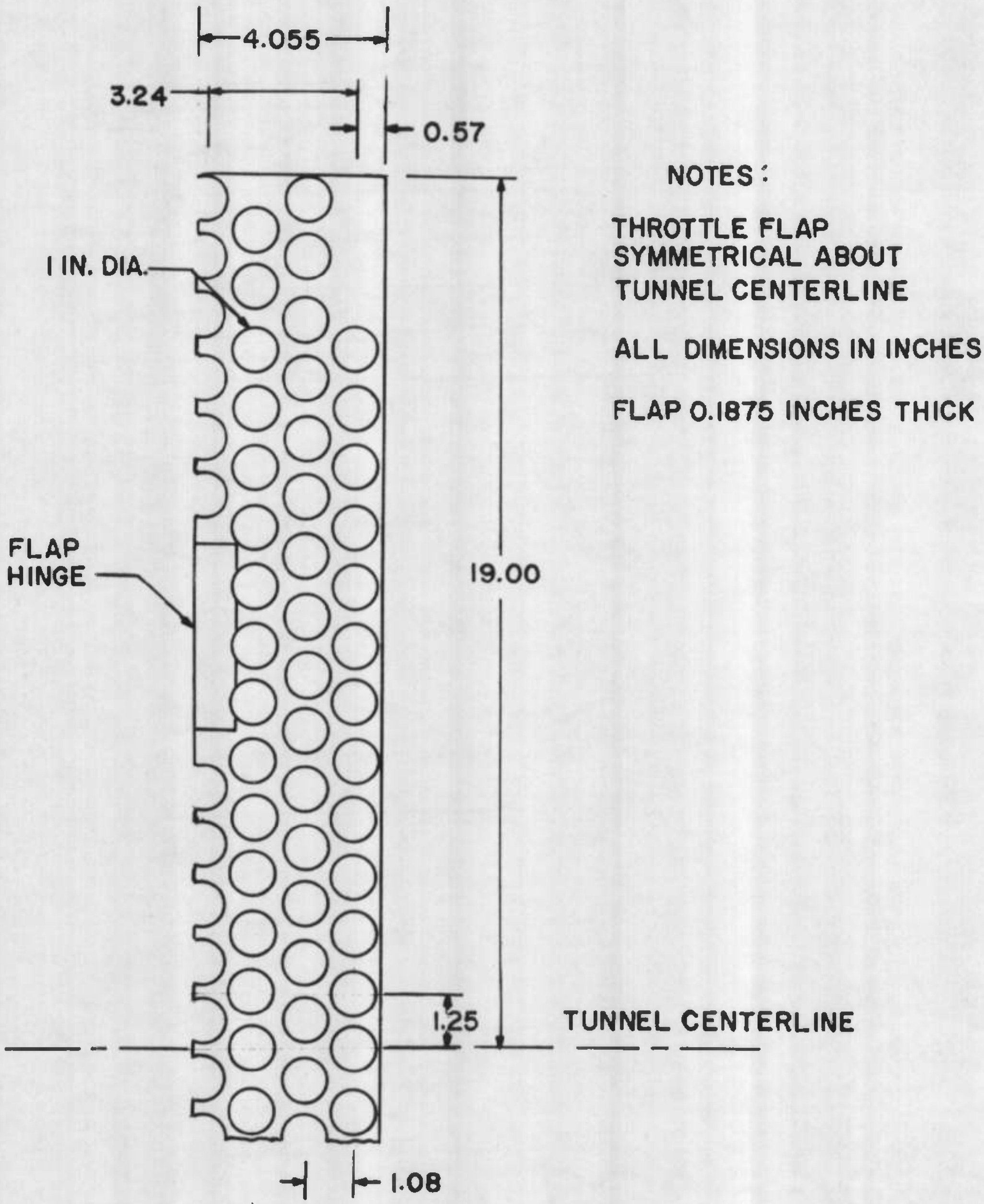
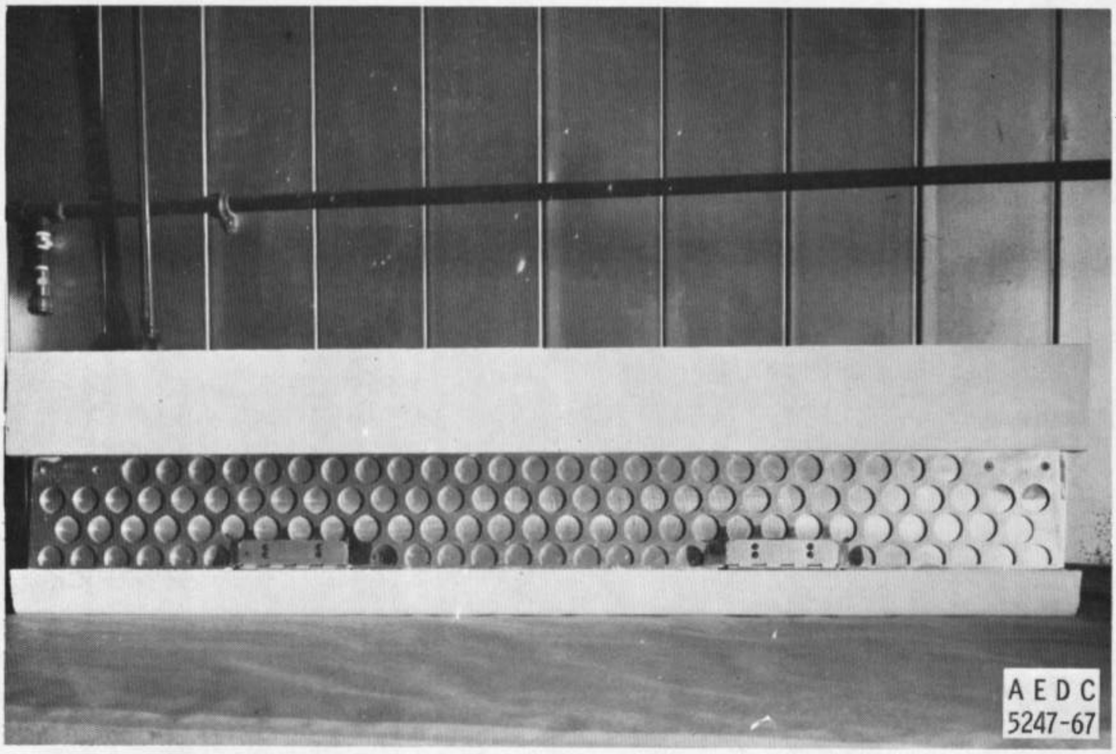


Fig. 4 Throttle Flaps



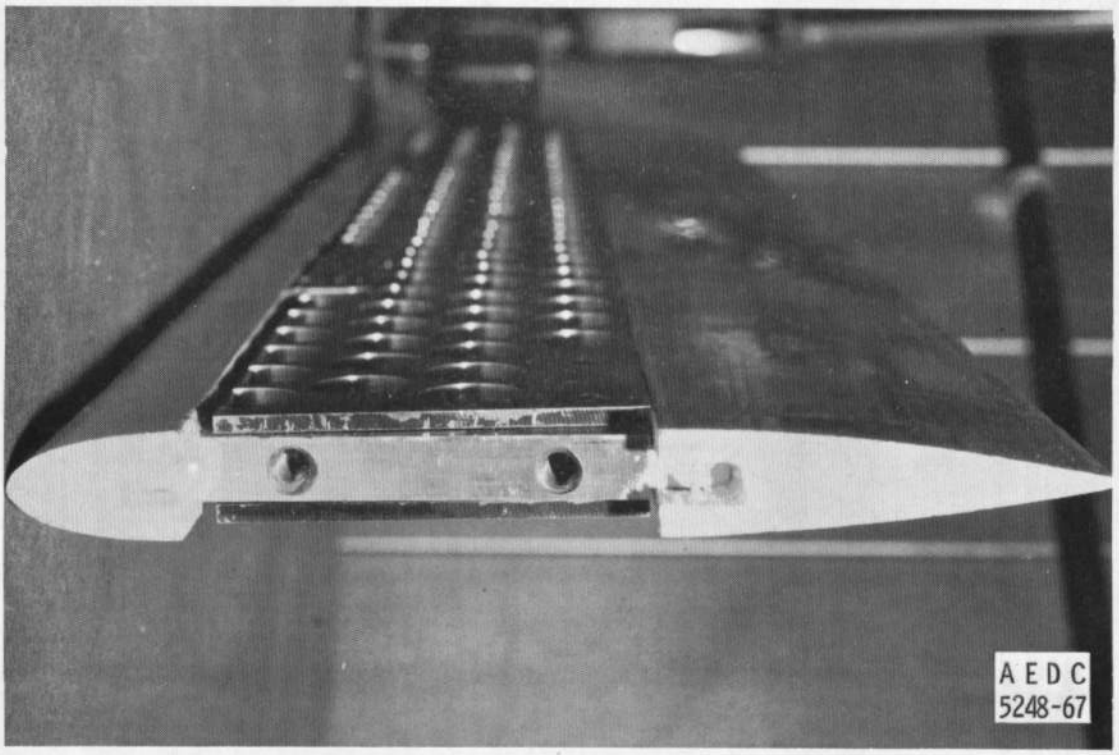


Fig. 5 Photographs of Throttle Vane

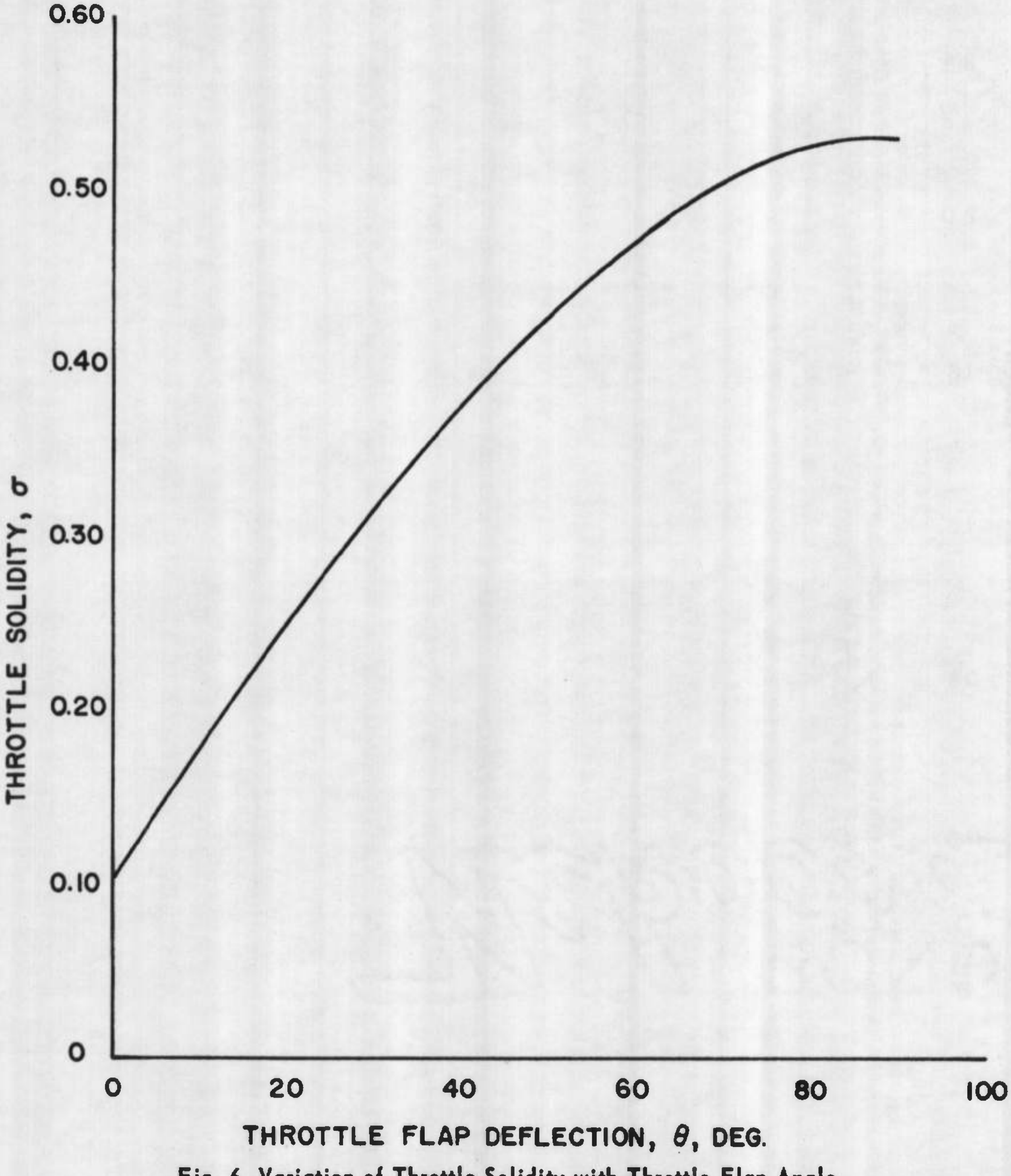


Fig. 6 Variation of Throttle Solidity with Throttle Flap Angle

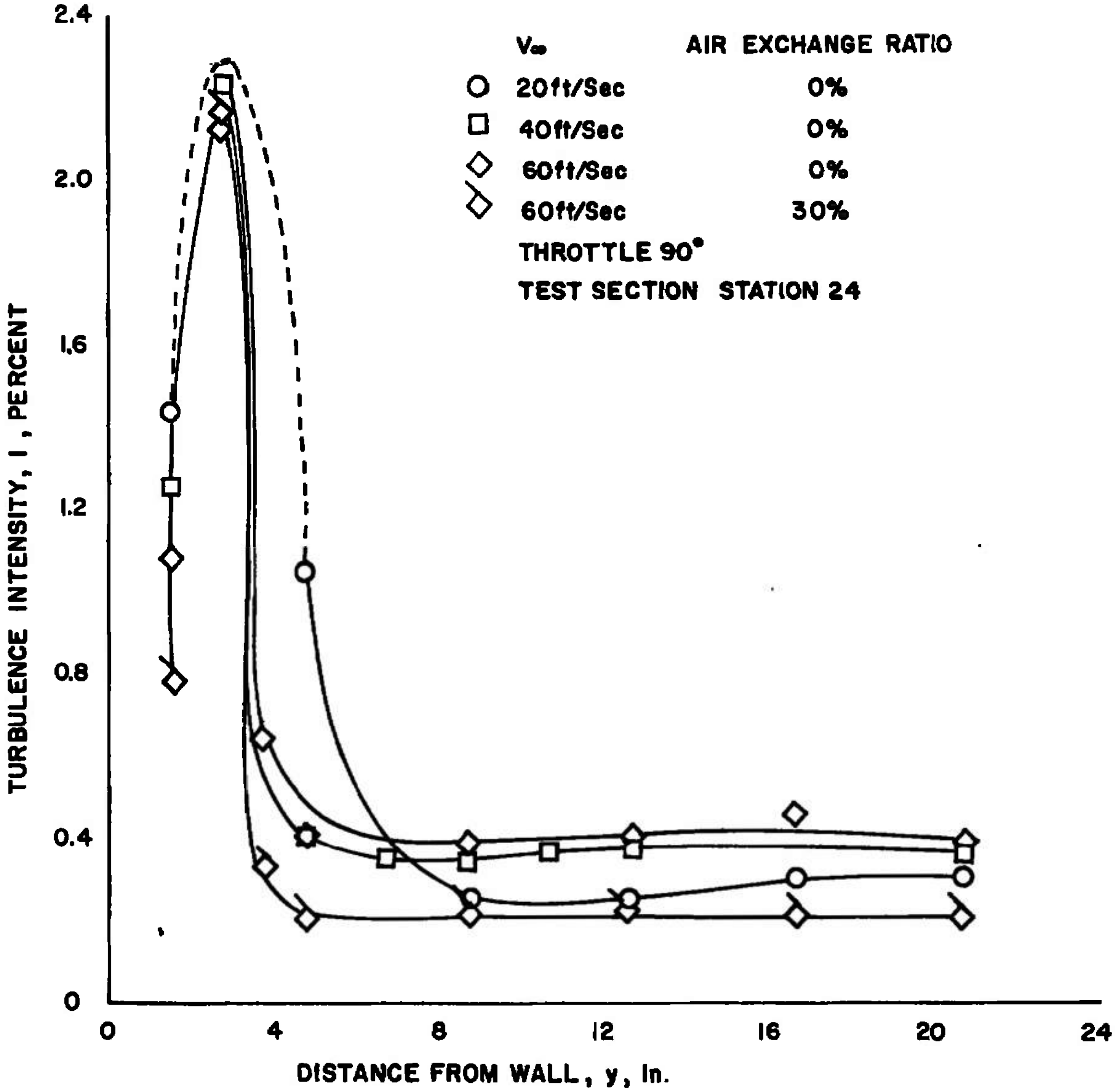


Fig. 7 Typical Variation of Longitudinal Turbulence Intensity with Distance from Wall

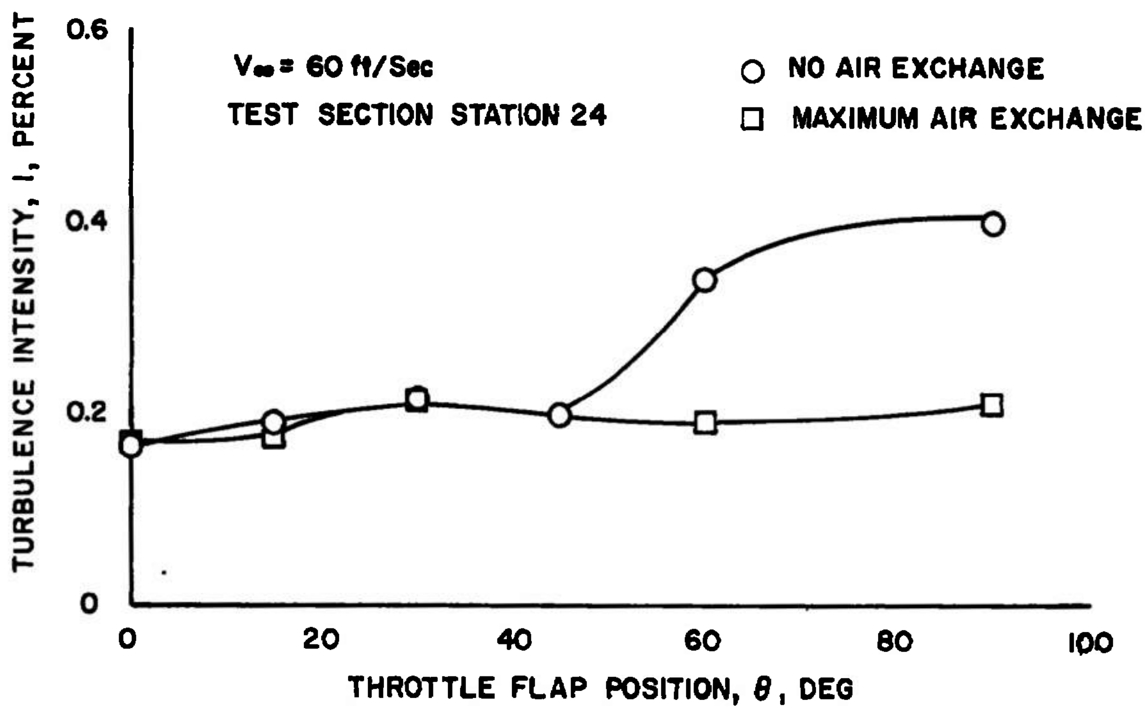


Fig. 8 Variation of Centerline Longitudinal Turbulence Intensity with Throttle Flap Angle

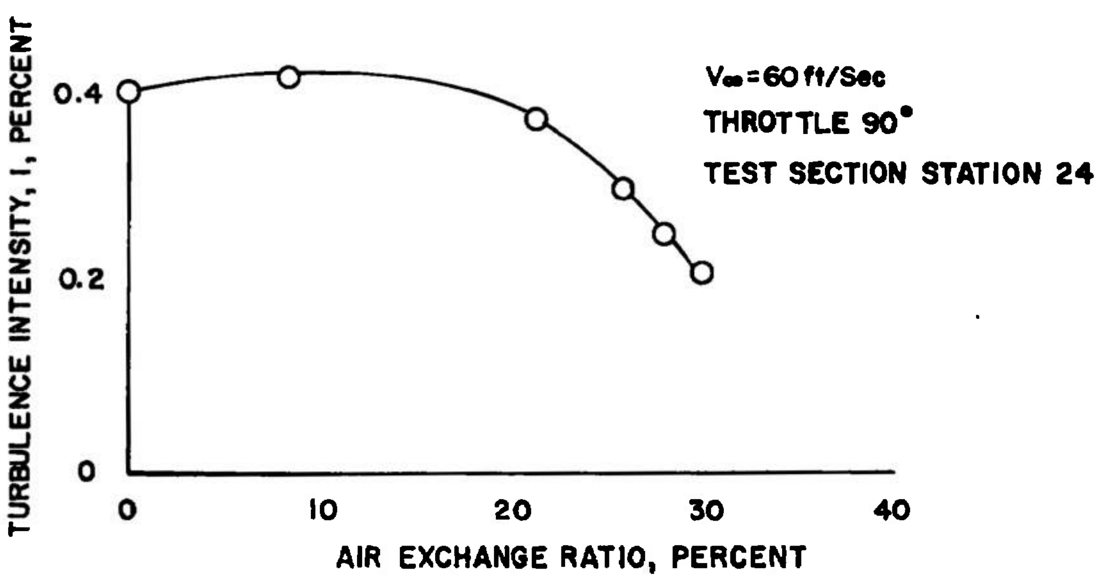


Fig. 9 Variation of Centerline Longitudinal Turbulence Intensity with Air Exchange Ratio

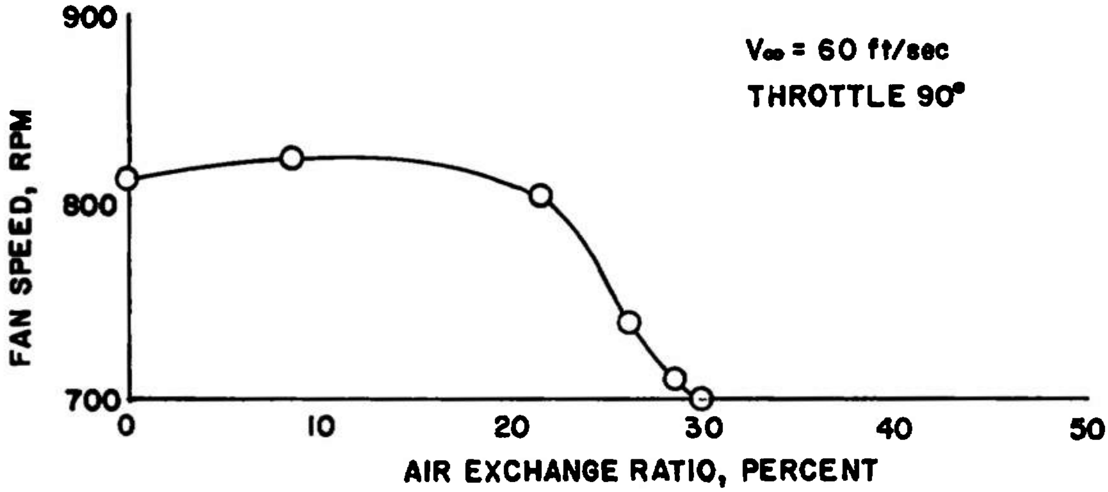


Fig. 10 Variation of Fan Speed with Air Exchange Ratio

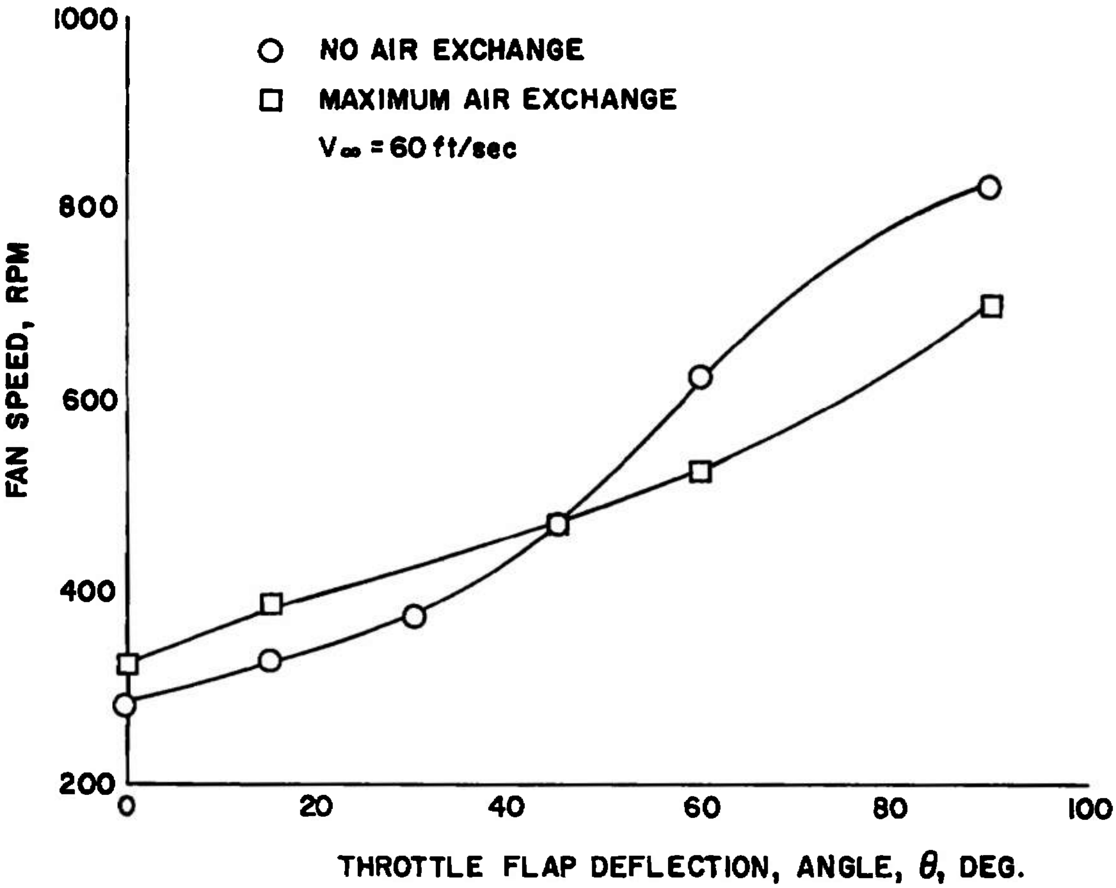


Fig. 11 Variation of Fan Speed with Throttle Flap Angle

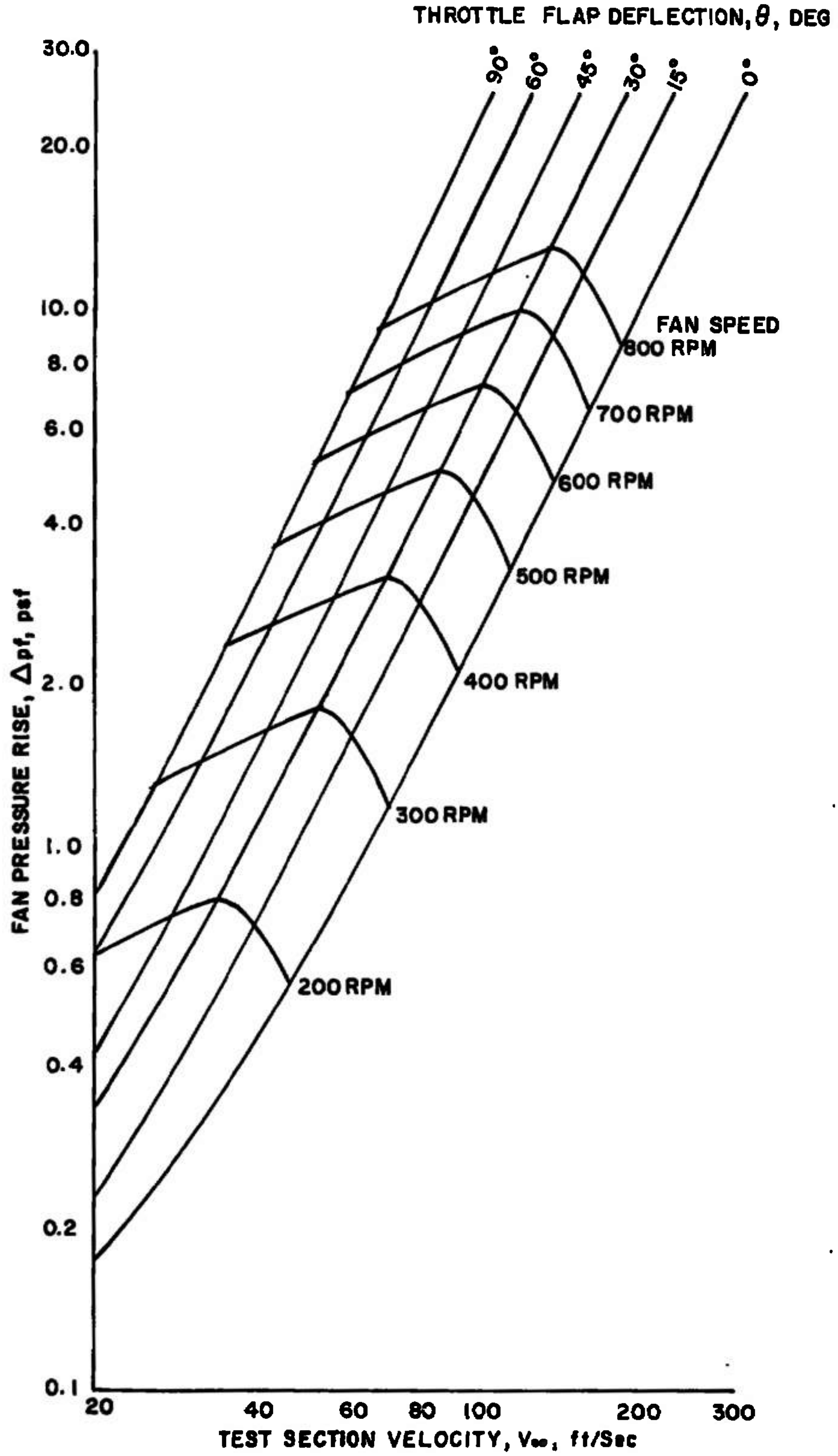


Fig. 12 Variation of Fan Pressure Rise with Test Section Velocity

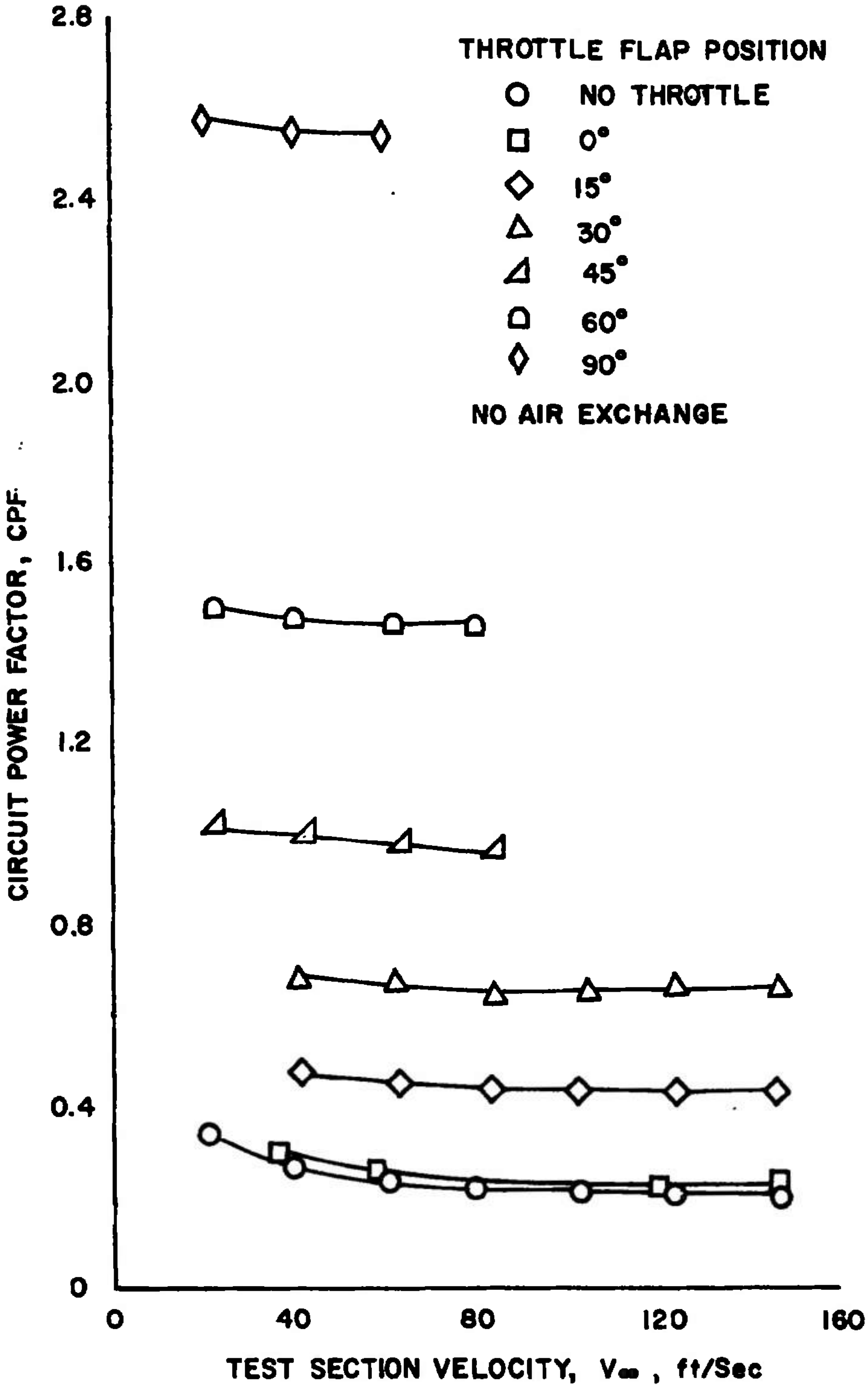
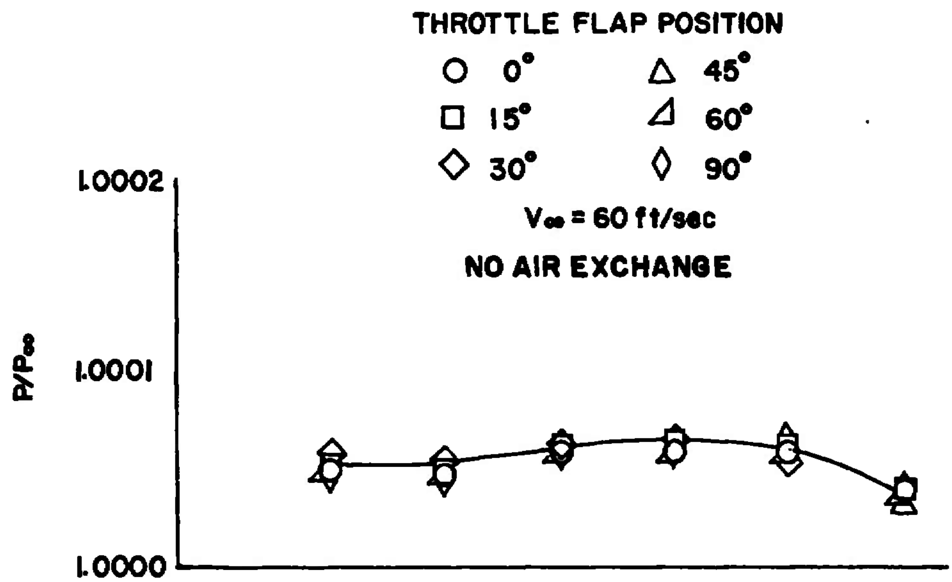
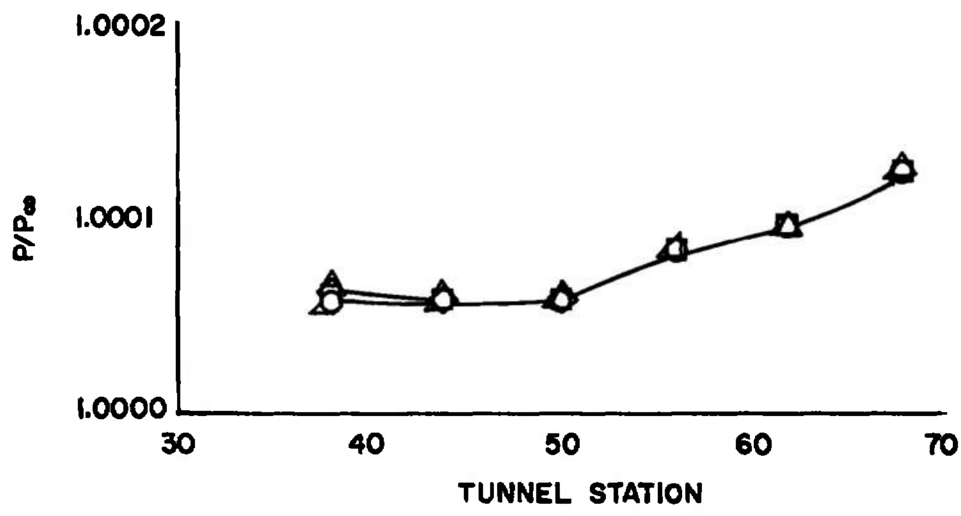


Fig. 13 Variation of Circuit Power Factor with Test Section Velocity



a. TOP WALL



b. SIDE WALL

Fig. 14 Test Section Longitudinal Static Pressure Distribution

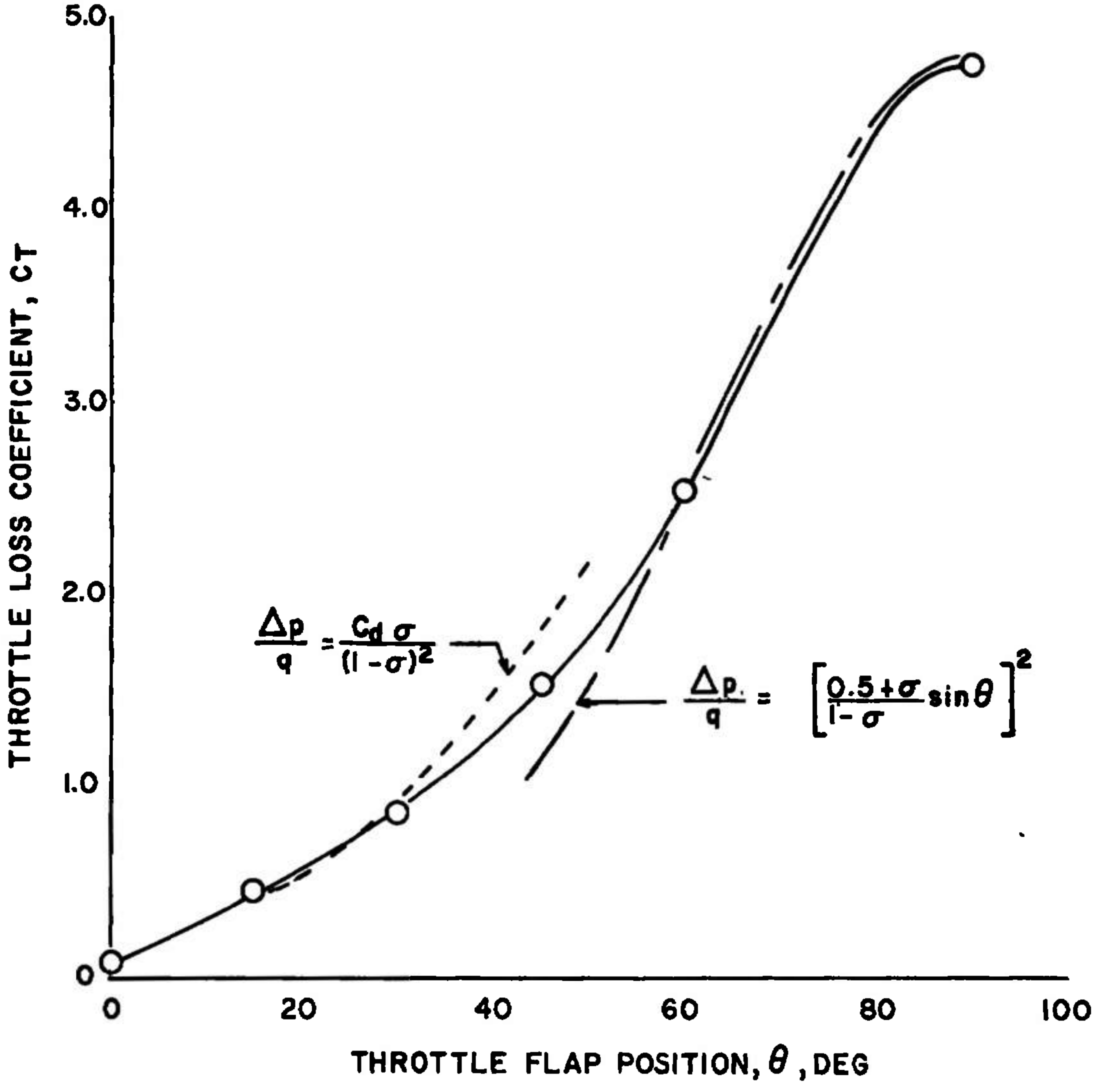


Fig. 15 Variation of Throttle Loss Coefficient with Throttle Flap Angle

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13. ABSTRACT

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